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# Tomas Lopez's geographic atlas of Spain (1787) and its hydrographic network: GIS analysis of the "Reyno de Jaen"

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## Abstract

*Knowledge of the development of hydrographic networks can be useful for a number of research works in hydraulic engineering. We thus, intend to analyse the cartography regarding the first work that systematically encompasses the entire hydrographic network: Tomas Lopez's Geographic Atlas of Spain (1787). In order to achieve this goal, we will first analyze –by way of the Geographic Information System (GIS) – both the present and referred historical cartographies. In comparing them, we will use the then-existing population centres that correspond to modern ones. The aim is to compare the following research variables in the hydrographic network: former toponyms, length of riverbeds and distance to population centres. The results of this study will show the variation in the riverbeds and the probable change in their denomination.*

## 1 Introduction

The historical context surrounding Tomás López´s cartographic work has its origins in the ascendance of Philip V to the throne of Spain and the establishment of his territorial policy. His prime minister, the Marquis of Ensenada (1702-1781), devised a set of reforms to improve the administration of the Spanish territories. To accomplish these reforms required a national cartographic base on which to quantify taxes. This political environment was crucial to the development of national cartography.

At that time, the theory that the Earth conforms to an ellipsoid of revolution (disproving the idea of a spherical Earth) was already known [1]. A dilemma arose as to whether the flattening of the ellipsoid was produced at the poles or the Equator. This led to expeditions run and financed by the Academy of Sciences of Paris in 1735 [2] to obtain conclusions regarding the real shape of the Earth. On the one side, the Cartesian theory presented by J.Cassini advocated flattening along the Equator while on the other the Newtonian theory argued that it occurred along the polar axis. For this, the measurements of meridian arcs in Quito (1735-1743) and Lapland (1736-1737), respectively were studied in parallel. Conclusions obtained from the studies sided with Newton and his "orange" model for the planet against Cassini´s "lemon" model.

A Spanish technical committee formed by Jorge Juan y Santacilia (1713-1773) and Antonio de Ulloa (1716-1795) was able to participate in the expedition to the Equator because the territories belonged to Spain. Subsequently, in 1751, Jorge Juan presented a report to the Secretary of State. In this report, he specified the scientific methodology that could be used for the creation of a general map of Spain at a scale of 1:100.000. A priority objective for the monarchy at the time was to provide to the eighteenth-century Spanish society with the knowledge that they demanded –accurate information about their territories´geography- through the dissemination of national and local maps. In this regard, Jorge Juan reported to the Marquis of Ensenada a concern that there was no qualified staff in Spain to collaborate on this project [3]. For this reason, it was a feasible measure for the Government to send representatives abroad to be instructed in cartographic techniques, and to amortize the measure politically with the subsequent production of cartographic material which would do a great service to the country.

Tomás López was one of those chosen for this important task. In the period between 1752 and 1760, as a beneficiary of the king, he studied in Paris under the teachings of D´Anville –famous cartographer to the French king- who in turn had been a disciple of F.Chevalier [4]. Both created a school of studio cartographers [5].

By the time Tomás López returned to Spain in 1760 to fully practice the profession he had learned, the Marquis of Ensenada had lost his position (in 1754) leaving his cartography project unfinished. López then began a successful career during which he produced more than 200 maps. Together with his sons, he founded the first cartographic publishing company, which was based at his home.

Charles III (1716-1788) appointed López as “Geographer to His Majesty´s Dominions” in 1770 as a result of the “interrogation” work that López had initiated in 1766. From that moment on, it was easier for him to access all existing information, having carte blanche to continue his tireless effort of data compilation throughout Spain [6].

López´s method -learned from his teacher D´Anville- is what has been called “studio cartography”. He has been branded as imprecise for dispensing with astronomical and geometric observations and for not supporting with field work the large volume of information he was able to gather [5]. He specialized in a compilatory methodology that united his talents for synthesizing and solving. Furthermore, during his training period in France, he had learned the art and craft of engraving very well and he used it in all of his works [7]. He created his maps from a collection of previously existing ones, which were supplemented with information from his “interrogations”. He sometimes created maps ex novo from this data. The “interrogation” was a questionnaire, directed at those responsible for each diocese or parish, containing 15 questions about the most relevant data, varied in nature, pertaining to their communities [8-9]. López requested a small map of a three-league radius surrounding each territory, in which all of this information was to be included [10].

The aim of this study is to check the cartographic accuracy of the hydrographic network in Tomás López´s work. For this we have used page number 64 of the Geographic Atlas of Spain (Spanish acronym AGE), corresponding to the Kingdom of Jaén, in order to compare it with the current hydrographic network. GIS will be used on two levels in order to analyze the degree of approximation of the information contained in the maps: first, the position of the population centres in Tomás López´s cartography relative to their current position. Secondly, the relative position of the hydrographic network with respect to the population centres in both cartographies in order to later make a final comparative analysis.

## 2 Methodology

Our methodology is divided in two parts: first, the analysis of the population centres on which the hydrographic network will be based (1-14) and, secondly, the specific methodology applied to the study of rivers (15-20). The software used in our work is ArcGIS 9 v.3.

Because each page of the Geographic Atlas of Spain (see Figure 1) was designed using a frame of graduated geographical coordinates of latitude and longitude, it is possible to georeference it in a space using a GIS. As preliminary work, we selected the reference ellipsoid. We chose the European Datum 1950 (ED50), which is based on the Hayford or International Ellipsoid of 1950 because most current maps of Spain are created with this reference. It is understood that the ellipsoid will not affect the accuracy of the map.

On the other hand, graphical scales are checked in both X (longitude) and Y (latitude) axes. It is found that the leagues to 20 degrees are identical in latitude but are reduced by a factor of 0.8 in longitude. This is valid for our ellipsoid ED50 at the latitude concerned.

### 2.1 Analysis of the accuracy of population centres

1.Georeferencing Tomás López´s scanned map using the frame: We georeference in GIS with the coordinates of the frame of page 64 (see Table 1)

| Page | Point | LATITUDE-Y | | LONGITUDE-X | |
|---|---|---|---|---|---|
| | | DEGREES | MINUTES | DEGREES | MINUTES |
| 64 | 1 | 37 | 30 | 13 | 0 |
| | 2 | 38 | 35 | 13 | 0 |
| | 3 | 38 | 0 | 12 | 15 |
| | 4 | 38 | 0 | 13 | 42.13 |

***Tab. 1 Points for georeferencing of page 64.***

2. Shifting the origin of latitude: We shift the origin of longitude from the Peak of Teide (the origin of longitude in López´s cartography) to the Greenwich Meridian (the origin in our comparative cartography). For this, we load and modify the frame of coordinates of step 2 and add to the geodetic longitude the value -16.6409096611º. With this we obtain an MSE (mean square error) of 0.00356 degrees for this plate, which would be equivalent to 0.3957 km (0.00356 degrees x 111.17773 Km/degree). This is due to possible errors in the graduation of the frame.

3. Digitizing Tomás López´s cities in geographic coordinates: The process of digitizing the different population sites, creating for each city a point-type graphical entity.

4. Calculation of coordinates and exportation of the Tomás López Cities database (Spanish acronym CTL): From this attribute table, the GIS can calculate latitude and longitude.

5. Importation of Current Population Centres (Spanish acronym NA) in geographic coordinates and ED50: The obtainment of the coordinates of the current population centres. For this, we used as a cartographic base the map of Cultivation and Land Use (Cultivos y Aprovechamientos) produced by the Andalusian Ministry of Agriculture and Fisheries (Consejería de Agricultura y Pesca de la Junta de Andalucía), corresponding to the province of Jaén.

6. Calculation of coordinates and exportation of the NA database: Using GIS, we calculated the coordinates of the current population centres and exported this second table.

7. Comparison of common toponyms between the CTL and NA databases: We process the data of both tables using the spreadsheet, ordering alphabetically both cities and population centres and grouping them into “matched” and “mismatched”.

8. Calculation of displacement between CTL and NA and average displacement in longitude and latitude: Once the search phase of matched and mismatched population centres and cities is finished, we have a total of 85 matching sites to work with. We then calculate in degrees the differences in longitude and latitude coordinates of both groups, and the average of these differences.

9, 10. Displacement of the average value in GIS, calculation of coordinates, and exportation of the CTL-Displaced database: Using GIS, we apply as the average displacement the average error in X and Y, for latitude and longitude, obtained in the previous phase. By doing this we can avoid a possible systematic displacement error in the absolute coordinates between both cartographies. Then, the coordinates of Tomás López´s cities are recalculated and re-exported.

11. Calculation of longitude and latitude errors in degrees, kilometers and total distance error: Longitude and latitude errors in degrees are computed and converted into kilometric distances, taking into account that 1 degree of latitude is equivalent to 0.8 degrees of longitude considering the sphericity of the Earth at mid-latitude 38º. Finally, the total distance error (ETd ) is calculated for each city:

ETd (Km)= √( x2+y2)

The scale obtained from the representation of the map (E), according to the estimation error (RMS= 2.7472 Km) follows the scale (E), as E= 1/M and 0. 2mm x M = error, then M = 2.7472 x 103 / 0.2 x 10-3 = 13. 7 x 106, ie E= 1/ 13.700.000.

12, 13, 14. Checking ETd<20 Km, selection and confirmation of verified cities: In this we make sure that there is no city whose ETd is greater than 20 Km. Any cities failing to meet this criterion are dismissed. Thus, 85 sites are considered as verified and a file is prepared with the coordinates and distance errors, in kilometres, of each "Ciudad Tomás López" ("Tomás López City").

## 2.2 Study of Rivers

15. Digitization of Rivers: Rivers are digitized and represented by line-type graphic entities.

16. Loading of current hydrographic network information: The current hydrographic network layer is imported from REDIAM, the environmental information network of the Andalusian Ministry of Environment (Consejería de Medio Ambiente de la Junta de Andalucía). This allows us to compare both networks, as shown in Figure 2 (magenta shows the current network and blue shows the network as drawn by Tomás López).

17. Preliminary observation of the hydrographic networks´ routes: Once both networks are observed, we can observe noticeable similarities, particularly in the principal water courses. However, we observe neither lineal overlaps nor overlaps in the relative locations of the water courses with respect to the previously referenced population centres.

18. Calculation of river buffers: After the above observation, we proceed to use GIS to analyze the relative location of population centres in relation to rivers. Because of the complexity of the network, this study is limited to the Guadalquivir River in the Kingdom of Jaén (Figure 3). Using GIS, areas of influence or buffers are drawn parallel to the rivers with a distance range from 0.5 Km to a maximum distance of 2 Km, both for Tomás López´s representation of the Guadalquivir River and the current one. The result of this process is shown in Figure 4, in which green shows buffers every 0.5 Km for López´s representation while blue does the same for the current river.

19. Intersection with matching population centres: The next step is to perform the intersection of these buffers with the matching centres obtained in step 7. This analysis is done independently for each river (the current river and Tomás López´s) because the existing displacements were already checked in the preliminary study of population centres. It would therefore not be logical to perform the intersection of both buffers because they do not have the same relative location. In this way we obtain the number of population centres contained within each river´s buffer.

20. Comparative study of matching population centres in each buffer range: In each of the four buffer ranges of the Guadalquivir River, we compare the population centres with those found within the same buffer ranges of Tomás López´s representation and calculate the number of them that overlap.

# 3 Results

In the preliminary study of the population centres, 160 sites of different rank were obtained from T.López´s cartography. Of these sites, a total of 85 (matching population centres) could be identified in the current cartography while 75 could not. In short, only 53.12% of the cities of Tomás López are identified with present ones.

As for the distance errors of the Tomás López´s cities with respect to their coincidence with their modern equivalents, it was observed that the minimum value of 1.4 km belongs to the population centre of Mancha Real and the maximum value of 17.9 km belongs to Santa Ana, in the South of the province.

In the analysis of the hydrographic network, given the linear nature of the entity and the level of inaccuracy found a priori in a visual inspection, a type of analysis has been chosen that correlates the location of the population centres within a band of approximation around the river. In this way, we obtain a percentage of agreement between both areas of influence depending on each established range and the population centres in the cartography with which is compared, whether it is Tomás López´s or the current one. We begin with the analysis of the 85 population centres that have been found to overlap between the two groups mentioned (Tomás López/current). These results are shown in Table 2.

| Buffer (Km) / Population Centres ∩ Rivers | 0.5 | 1 | 1.5 | 2 |
|---|---|---|---|---|
| TOMÁS LÓPEZ (A) | 1 | 3 | 6 | 8 |
| CURRENT (B) | 5 | 10 | 10 | 13 |
| A ∩ B (C) | 0 | 3 | 6 | 7 |
| % C with respect to A | 0 | 100 | 100 | 87.5 |
| % C with respect to B | 0 | 30 | 60 | 53.85 |

***Tab. 2 Results of GIS analysis, intersection of the Guadalquivir River with the population centres of both cartographies***

Although at first glance (Figure 3), it seems that the two representations of the Guadalquivir River bear little resemblance to each other –as there is a large difference between the two paths, the GIS analysis shows the following:

Regarding Tomás López´s cartography, there are no overlapping centres for a 0.5 km area of influence despite the fact that both cartographies contain population centres within that area of influence. Therefore, we can assume that the representation of the proximity between rivers and population centres in Tomás López´s cartography is beyond that distance. If we converted this distance to leagues, that figure would be 0.09. Bearing in mind that this is a work of studio cartography composed of three-league diameter sketches, the accuracy achieved in this type of cartography is surprisingly adequate in terms of baseline information.

Paradoxically, increasing the area of influence of the river should increase the number of overlapping population centres between the two maps. Nevertheless, this does not occur (see Figure 3) as to the right we can observe a diversion of Tomás López´s river toward the north. Thus, when we increase the areas of influence, we find more than 85 overlapping population centres between both cartographies, but the rate of intersection of the population centres does not increase because of López´s error in charting the river´s path.

## 4 Conclusion

We see how after more than two centuries, thanks to geographic information tools, it is feasible to return to the Geographic Atlas of Spain to analyze it and obtain very interesting results when contrasting them with the currently known information. While providing new information, this work is also useful in proposing a methodology of analysis based on GIS that makes it possible to analyze the paths of rivers with respect to their proximity to population centres. The method used in the cartographic analysis is systematic and rigorous as it always uses the coordinates of the cities and population centres of the different sites. Working with large areas is easier thanks to the power and versatility of the GIS tool, which allows us to manage all data associated with each point in the territory. It offers a wide range of possibilities for processing, analyzing and presenting results.

The results obtained in this work have shown that only 53% of the population centres overlap in both cartographies. Taking into account the calculations made with the sample of 85 matching centres of population, errors in distance with an average of 7.5 km are obtained. A lack of homogeneity can be seen in the map scale, which is very obvious after the study of the rivers.

The accuracy achieved by this studio cartography in the studied hydrographic network, the Kingdom of Jaén, is unexpectedly adequate in terms of baseline information, as the population centres of this cartography are relatively well located regarding distance from the river. The errors in this map can be attributed to the sources of López´s work and his processing of information, a key point in the cartographer´s methodology. T. López described himself as a "studio geographer" and based his maps on pre-existing ones which he completed using the information he obtained through his questionnaires.


***Fig. 1 Kingdom of Jaen. Tomás López. 1787.***

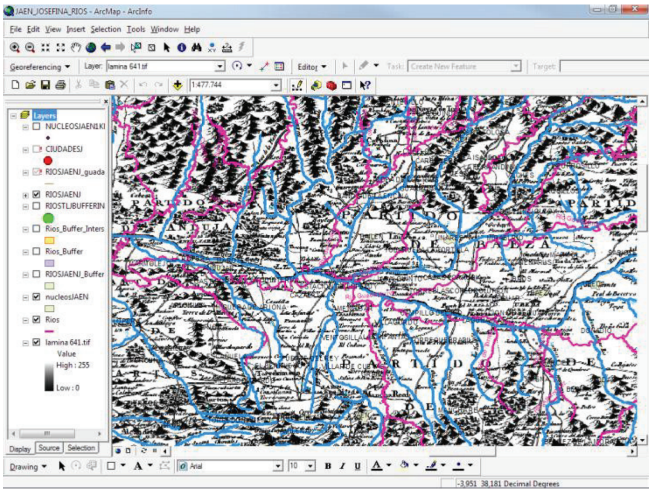

***Fig. 2 Hydrographic networks in the Kingdom of Jaén (—— current network; —— T. López´s network)***


***Fig. 3 Overlay of the route of the Guadalquivir River (—— T. López´s network; —— current network).***

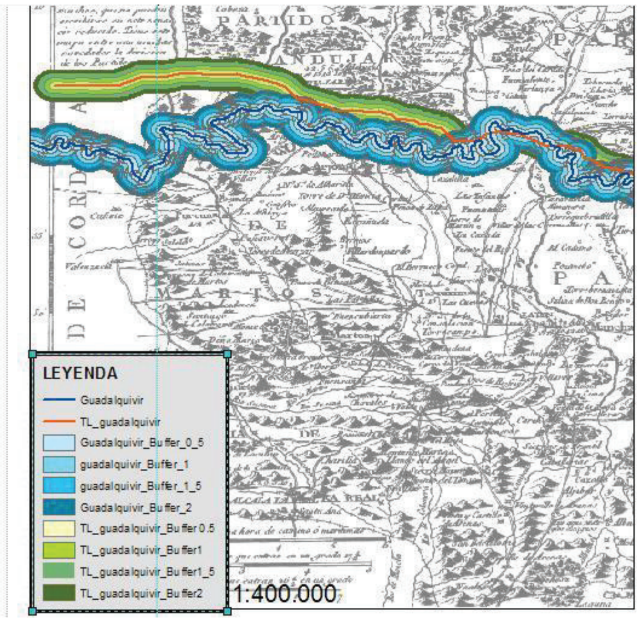


***Fig. 4 Overlay of the buffers drawn for both Tomás López´s representation of the route of the Guadalquivir River and the river´s current route (—T. López´s network; —current network).***

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The digital image of the Kingdom of Jaén has been provided by the CNIG (Spanish Centre for Geographic Information) from the facsimile edition of Tomás López´s Geographic Atlas of Spain, which was published in 2005 by this organization.

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